Transition into a low temperature superconducting phase of unconventional pinning in Sr_2RuO_4

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Abstract

We have found a sharp transition in the vortex creep rates at a temperature $T^* = 0.05T_c$ in a single crystal of Sr_2RuO_4 ($T_c = 1.03\,\mathrm{K}$) by means of magnetic relaxation measurements. For $T < T^*$, the initial creep rates drop to undetectable low levels. One explanation for this transition into a phase with such extremely low vortex creep is that the low-temperature phase of Sr_2RuO_4 breaks time reversal symmetry. In that case, degenerate domain walls separating discreetly degenerate states of a superconductor can act as very strong pinning centers.[1]

The discovery of superconductivity in Sr_2RuO_4 in 1994[2], a material structurally similar to the high-T_c superconductor $(La_{1-x}Sr_x)_2CuO_4$, provided the first example of a layered perovskite without copper which becomes superconducting. The strong interest in this material is based on the suggestion[3] that Sr_2RuO_4 could constitute the first example of odd parity ($l = 1$) superconductivity. The suggestion was based on the fact that in the normal state above T_c, Sr_2RuO_4 behaves like a quasi-2D Landau Fermi liquid

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with many-body enhancements of the specific heat and the Pauli spin susceptibility similar to another Landau Fermi liquid, namely normal liquid ^{3}He below about $T = 100$ mK. At present, there is no experimental evidence for tripplet pairing in Sr_2RuO_4. Some hints of unconventional pairing come from measurements of the specific heat[4]. In the cleanest samples it is found that in the superconducting state, the residual electronic specific heat remains at about 50% of its normal value. Furthermore, NQR measurements show no indication of a Hebel–Slichter peak in $1/T_1T$[5] and also T_c is strongly depressed by non-magnetic impurities[6].

Recently we investigated the magnetic properties of the unconventional superconductor UPt_3 by means of magnetic relaxation measurements on high quality single crystals[7]. We found out that in the low temperature B–phase, where a small spontaneous magnetic field has been observed in μSR experiments[8], no creep could be detected from any metastable configuration for about the first 10^4 seconds. Above the temperature at which the second jump in the specific heat occurs, we observed a different vortex regime. In this regime, the initial vortex creep is finite with a rate that increases rapidly as the temperature approaches the transition temperature T_c. We interpreted the zero initial creep rate in the low–temperature, low–field B–phase of UPt_3 as resulting from an intrinsic pinning mechanism where fractional vortices get strongly trapped in domain walls between domains of degenerate superconducting phases.

These experimental results show that the widely different pinning strengths can be used as an indirect information on the character of a given superconducting phase. Superconducting phases that break time reversal symmetry might then be identified by their lack of vortex creep or their anomalous strong pinning.

We present here similar measurements of the relaxation of the remanent magnetization on a single crystal of Sr_2RuO_4. The experimental arrangement has been described in a previous publication [7]. The single crystal has a transition temperature $T_c = 1.03$ K. The magnetic field in these measurements was applied at an angle of 15° from the basal plane. All the values of M_{rem} were taken with the specimen cycled to sufficiently high fields, so that the sample was in the fully critical state. In the insert of Fig. 1 we give decays of the remanent magnetization normalized to the value of M_{rem} at $t = 1$ s at different temperatures. We observe that in the first couple of thousand seconds M_{rem} relaxes following a logarithmic law. At longer times one observes a more rapid relaxation, similar to what we found in UPt_3. This long time

rapid relaxation is due to surface vortices[7]. Here we only discuss the initial slopes of the decays which are determined by creep of bulk vortices. The normalized creep rates $S_{initial} = \partial \ln M / \partial \ln t$ for Sr_2RuO_4 are given in Fig. 1 as function of temperature. We observe two different regimes of vortex creep separated by a rather sharp transition around $T \approx 50\,\mathrm{mK}$. For $T < 50\,\mathrm{mK}$ the creep rates fall to zero within our sensitivity ($\partial \ln M / \partial \ln t \approx 10^{-5}$). Above $T \approx 50\,\mathrm{mK}$ the creep rates are finite and increase rapidly as the temperature is increased. In Fig. 2 we display the same data in a double logarithmic scale. For comparison we have also plotted vortex creep rates of an $YBa_2Cu_4O_8$ single crystal[9] where the creep rates are much stronger and they tend to a finite value for $T \to 0$ on account of quantum tunneling.

Based on our previous result of no observable creep in the low temperature superconducting phase of UPt_3 we propose that the sharp transition in Sr_2RuO_4 at $T \approx 50\,\mathrm{mK}$ into a phase with very strong pinning might have a similar physical origin. Work on more samples is under way to confirm these preliminary results.

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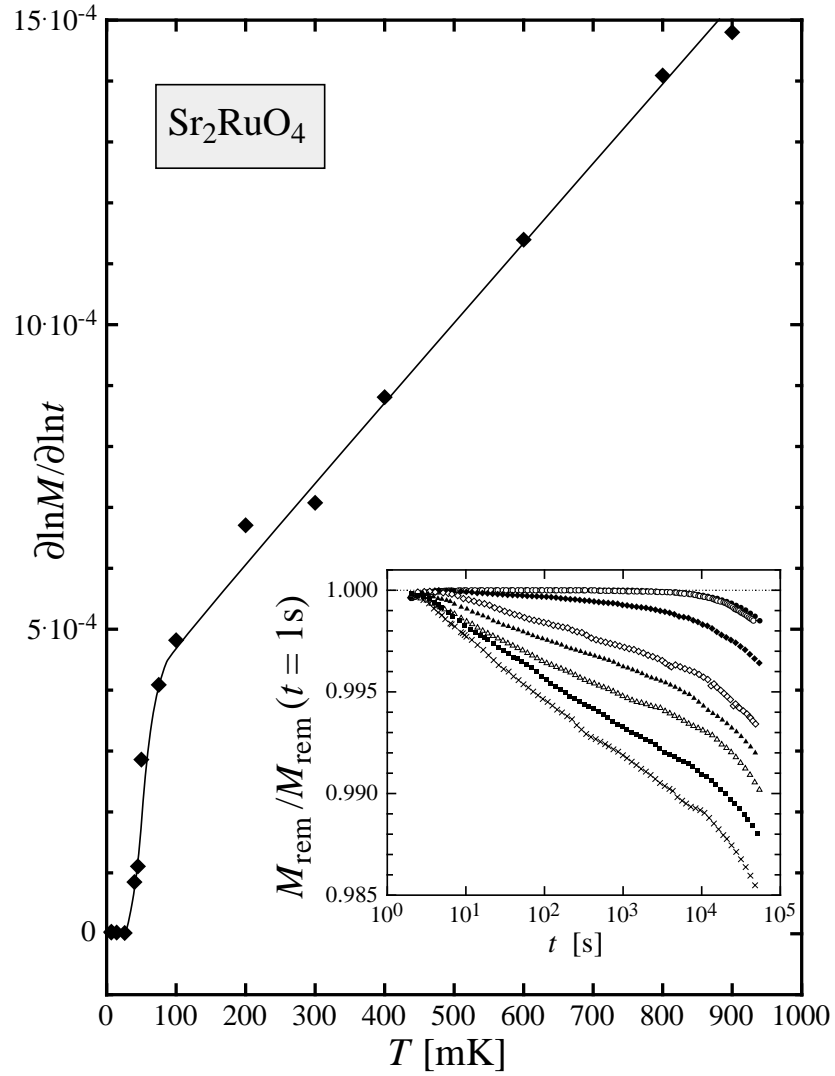
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Figure 1: Initial creep rates vs T. The inset shows decays of M_{rem} for $T = 6.7 \, \text{mK}$ (closed circles), $26 \, \text{mK}$ (open circles), $45 \, \text{mK}$ (closed diamonds), $100 \, \text{mK}$ (open diamonds), $200 \, \text{mK}$ (closed triangles), $400 \, \text{mK}$ (open triangles), $600 \, \text{mK}$ (closed squares), and $800 \, \text{mK}$ (crosses).
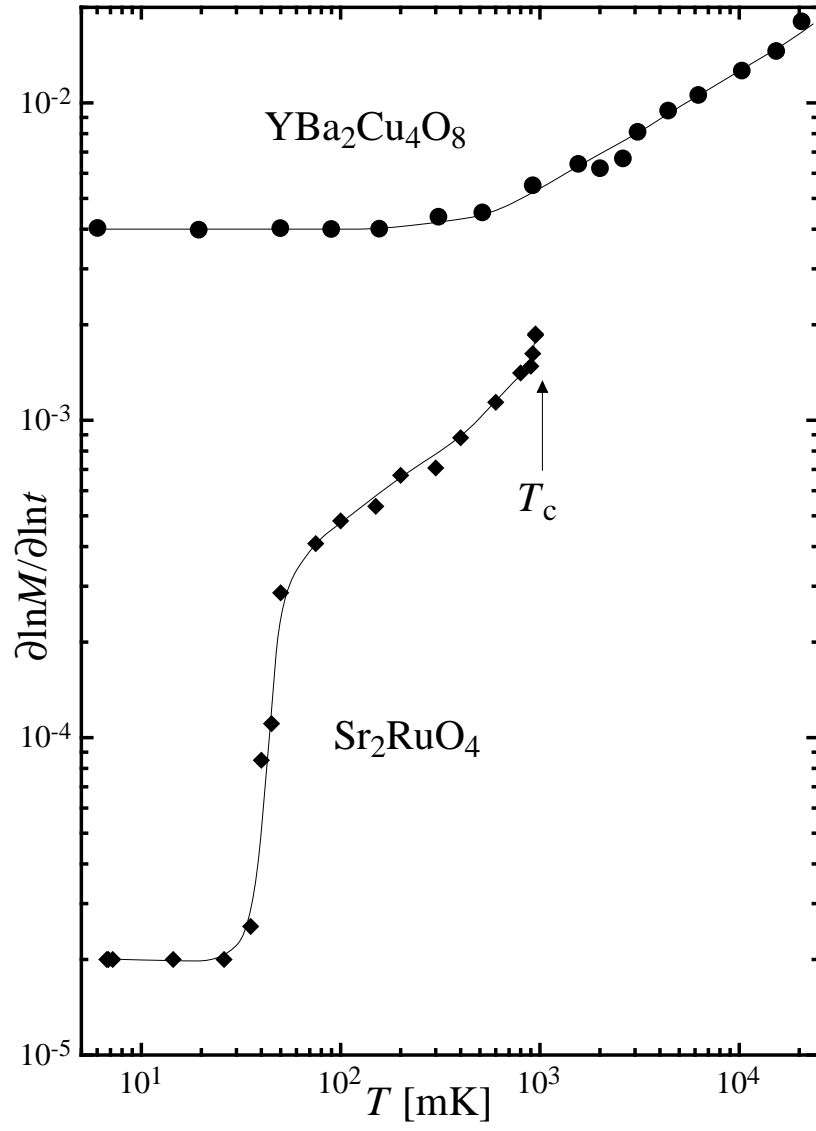
Figure 2: Creep rates of $YBa_2Cu_4O_7$ and Sr_2RuO_4 vs T.